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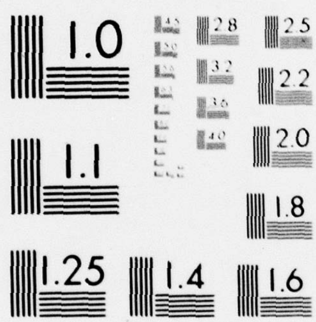
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THE VITAL FUNCTION CONCEPT IN THE DESIGN OF NAVAL SHIP

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ABSTRACT

This paper will define the concept of vital functions as applied to ship design. A list of vital functions is proposed and methods which are currently used to protect these functions are listed. Finally, a short procedure is given which can identify vulnerable parts of a functional area and suggest types of protection.

Naval Ships are designed with much built-in protection. The vital functions concept is introduced here as part of an approach which will help to make this protection consistent for a given function. The functional approach does not isolate the different systems, spaces, and personnel which all provide service to the same function. This kind of a total look will help identify vulnerable points in the ship design.

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The Vital Function Concept in the Design of Naval Ships

Introduction

Throughout its history the United States has built ships to fight battles at sea. Naval combatant ships, and the auxiliary ships and craft which support them, are built with the express purpose of seeking out the enemy at sea and destroying him. Although it is hoped that the fighting ships will never see the heat of battle, they are so designed, built, exercised and prepared.

All ships including naval ships are designed to withstand the normal perils of the sea: wind, waves and weather, and to withstand, to some extent, stranding, collision and human fallibility. However, only naval ships may be required to accept these hazards in time of conflict or emergency when they cannot be avoided and when battle damage is imminent. The naval ship cannot always run from natural perils; she is designed to continue to function under the harshest of conditions.

The designers of naval ships have always worked to reduce the vulnerability of their design. One mission of the ship, to seek out and destroy the enemy, today requires many complex systems which must be protected. The naval ship presents a threat only if these systems can continue to operate in the heat of battle. Thus naval ships are designed to take punishment. The continued, sustained projection of sea power depends on tough ships which can resist the elements; which can protect the men who fight them; which can accept damage, be repaired and fight again; and which can resist damage due to shipboard accidents. This toughness can be examined by looking at the functions performed by the ship.

Definition of Vital Functions

The ship's systems can be organized by function. Functional breakdowns have often been used to deal with the ship's complexity for various design purposes, and can also be used to deal with vulnerability. The word "functions" rather than "systems" or "spaces" is used because it is a general term. Included within the idea of "functions" are "systems" and "spaces", as well as attributes such as "visibility from the pilot house", or "access for fire fighting purposes". Both visibility and access are functions which can not really be termed a "space" or "systems." Some functions may be considered to be more important than others since they are directly related to survival of the ship, ship mobility and the ability to fight. These functions which are essential for the ship's mission may be called vital functions.

Vital functions are those which are necessary for the continued operation of the ship. The idea of vital functions has appeared in the General Specifications for Ships of the United States Navy as part of the requirement for vital spaces. Five vital functions are listed, they are:

- Ship Control
- Propulsion
- Communications
- Seaworthiness
- Combat Capability

Vital functions are highlighted so that we can give them added viability. A space such as the Combat Information Center (CIC) contains vital equipment and houses men who perform vital operations. This space should be protected more than a storeroom or an office. A vital function such as fire fighting depends on the fire main which thus should be given more attention than the fresh water system.

I hope in this paper to illustrate how the idea of vital functions applies to existing ships and how it can be applied to new ship designs. In existing ships it is a useful way to organize existing protective measures to evaluate their effectiveness. In new ship designs, the idea can be used to give reduced vulnerability. From the idea of vital functions we can identify vital systems, spaces and attributes which can be given protection once they have been so identified. A list of vital functions is proposed and a short evaluation sequence is given which can be used to aid in providing effective protection.

Ship Protection Measures

Most studies of vulnerability have identified methods of protection which apply in general to all kinds of systems. These are described below, followed by a discussion of how they apply to existing ship designs. These basic design ideas which are used to give protection to vital functions are:

- Redundancy
- Segregation
- Consolidation
- Protection

These ideas are often combined, as when redundant parts of a system are segregated. One of these measures, protection, can be given by mechanical means such as armor, the others depend on arrangement.

Redundancy - Redundancy in a design is achieved by including more than one means to accomplish a function. This includes various types of back up systems as well as duplicate systems.

Segregation - This term covers the breaking up of a system into parts; as well as separation, providing a protective distance between functions.

Consolidation - Most systems have a number of parts in series. If any one of the parts in series is destroyed, the system cannot function. To achieve reduced vulnerability, since none of the parts is useful without the others, they are located close to one another. This way they present a small target and may be more effectively segregated from redundant systems.

Protection - Armor and shock mounting are forms of protection, a material form of defense against mechanical damage.

Protection of Vital Functions

The Navy's current design practice includes all four of these ideas in many different forms. Also, many features of ship design, not primarily intended to reduce vulnerability, do so. Forward and after gun mounts may be included to provide 360^{o} coverage but they also are redundant. Valves in some systems may be intended to simplify repairs, but they also make it possible to segregate damaged parts of the system. An expanded list of vital functions is included below so that current design practices which protect vital functions can be discussed:

Seaworthiness
Ship Control
Propulsion
Manpower
Structural Integrity
Damage Control
Access
Combat Capability
Sensors (Radar, Sonar)
Communication
Power & Lighting
Ventilation
Enclosure of vital spaces
Chilled Water

Seaworthiness - One aspect of seaworthiness is the ability to remain afloat. Ships are segregated into watertight compartments to limit flooding; in addition, they may be protected by armor belts or other passive protective systems.

Ship Control - Steering may be controlled from the bridge or from after steering and many ships have a Secondary Conning Station. Larger ships have two or more rudders. In the steering gear room, there are generally two hydraulic pumps and control mechanisms which may receive signals from either of two ship control cables. This is backed up by a hand pump and, if the hand pump fails, chain falls can be used to move the rudder. The hydraulic pumps have several back up means of receiving electrical power. Usually more than one radar system is installed for ship control. Several repeaters are included. CIC generally contains more than one analog plotting board which can be used for maneuvering. The visual conning by the Officer of the Deck (OOD) on the bridge backs up the plot in CIC and vice versa.

Some amount of segregation in ship control is achieved by locating CIC away from the bridge. The steering control cables are run on opposite sides of the ship.

Propulsion - The propulsion function is made redundant by incorporating multiple propellers, or if a single shaft is used, by providing auxiliary propulsion units.

The propulsion machinery for each propeller is usually consolidated in a separate space and may be protected by armor or a side protection system.

Manpower - Current training systems are designed to provide some redundancy by cross-rate training. This type of training, for example, gives the machinist mate some idea of how the electrician's job relates to his. Usually, more than one person is qualified for a given job. Further redundancy, segregation and consolidation of manpower accompanies redundancy, segregation and consolidation of the systems which are served.

Methods of protection may include protective clothing, Oxygen Breathing Apparatus (OBA's), airline masks, means of escape, emergency lighting systems and the air tightness, water tightness, and ballistic protection afforded by ships' structure.

Structural Integrity - Design factors are a form of redundant design. The need to protect aluminum structures from high temperatures is becoming increasingly a part of design practice.

Damage Control - There are many redundant features in damage control. The many pumps supplying the fire main, its port and starboard segments and the many fire plugs are all redundant features. There are several repair stations which can back each other up. Halon systems have reserve bottles for a second shot capability. Hangar deck sprinkling systems are supplied from multiple locations of the fire main.

Segregation is accomplished by damage control valves. Fire pumps and AFFF stations are separated.

Protection for a single segment fire main is provided by locating it near the centerline.

Access - In many manned spaces redundant egress is possible through escape scuttles. The escape is separated as much as possible from the main access. Accesses to vital spaces are protected by making them watertight to the flooding water levels and by insulating the escape trunks from main machinery spaces.

Combat Capability - Multiple weapons systems provide redundancy. Many systems can be controlled from several locations. The weapons systems may be separated by their location on the ship.

Sensors - Sensors may be made redundant, for example, by including designated radar systems which have overlapping capability. Sensors are separated by their location on the ship and their associated equipment is protected by vital space provisions.

Communications - Redundancy varies but there are a number of systems which have overlapping capability including the MC systems, dial telephone, and many sound powered phone systems. The MC systems and sound powered phone systems are separated into various circuits. The sound powered phones operate through several switch boards. Ship to ship communications may be through a number of different radio transmitters, flashing light, signal flag, semaphone or megaphone. All communication wiring is protected by the ship's structure.

Power and Lighting - Vital services can have up to three sources of power: normal, alternate or emergency, and casualty power. Some systems have batteries as a back up power source. There are several ship's service generators and emergency generators. Normal lighting is backed up by emergency lighting and battery powered battle lanterns.

The electrical system can be segregated by opening bus tie breakers to isolate damaged portions. The generators are separated by their location on the ship. Normally the main power cables are run in a loop and are separated horizontally and vertically. The cables are run to take advantage of existing structural protection and to avoid hazardous areas.

Ventilation - Natural ventilation provides some redundancy for forced ventilation. Recirculating air conditioning for some vital spaces is provided by multiple sets of cooling coils. Consolidation in recirculating air conditioning has occasionally been provided by locating a designated unit within or adjacent to the vital space it served.

Enclosures of Vital Spaces - Vital spaces may be separated by airtight or watertight bulkheads or by distance within the ship.

Vital space bulkheads are airtight or watertight and aluminum bulkheads may be protected by insulation to resist the entry of heat, smoke and flame.

Vital Functions Design Approach

How can we improve the protection of vital functions? Most of current methods which are a part of design practice have developed in response to a need or are the result of good engineering judgment. Recently, systematic approaches have become popular and have been applied to the vulnerability problem. However, accidents continue to cause costly damage to ships. The accident damage is almost the only evidence we have of the capacity of ships to withstand damage since few modern United States capital ships have sustained battle damage. Ships of foreign navies have been involved in isolated incidents but have not been examined by United States designers. Accidents repeatedly prove to us that ships need improved protection. Protection is expensive, redundant systems, added armor and thermal insulation add to the topside weight and to the cost, which is already excessive. Systematic methods to define the need for protection by matching a threat to a level of need for each vital function, can be devised to provide the most efficient protection for a given cost.

A systematic approach would first rank the vital functions in order of importance to the survival of the ship. For example, a ranking might be:

1. Functions which keep the ship afloat.
2. Functions which propel and maneuver the ship.
3. Functions which enable the ship to perform its mission.

Next, the threats to each function would be ranked in the order of which would cause the most damage. Threats might include the possibility of flooding, fire damage, ruptured piping destroying electronics equipment or explosions in nearby magazines. The threats would be balanced against the importance of the function to establish protection priorities. The combination of function and threat which receives the highest rating of combined threat and importance would receive the greatest protection from that threat.

At this point the designer would consider what sort of protection to apply. Various criteria could be used to decide which protective measure is most efficient. Depending on the ship type or the economic environment, least weight, least cost, least rise in center of gravity (KG) or some other criterion or combination of criteria could be used.

This kind of a comprehensive approach has some disadvantages. It becomes a long and tedious process which can best be performed by the computer. The actual damage done by fire or explosion is difficult to predict as is the effectiveness of the protective measures. Invariably assumptions have to be made which will affect the outcome of the process. There is also the problem of precision; e.g., trying to rate the degree of vulnerability of a system on a scale from 1-5 when it is more realistically rated on a scale of 1-2. Finally, the results of such an analysis are difficult to test. In fact, such testing would probably require the destruction of several ships.

At the present time the Navy does use a system of computer programs which can estimate the effects of ballistic damage on the functional operation of the ship, and is developing a model for fire spread damage. Thus the Navy relies on the combined computer outputs, experienced engineers and established design practices for ship protection. When an engineer is developing his design for a new ship system, he should from time to time review it and decide whether it is insufficiently or excessively protected. He should break down his system so that it becomes apparent what parts are vulnerable and what methods he can use to add protection. The following questions can aid in this kind of analysis:

I. Is this system necessary for the performance of a vital function?

II. How much segregation is needed?

- a. Can the vital parts be <u>segregated</u> from the non-vital parts?
- b. Can damaged parts be <u>segregated</u> from undamaged parts?

III. How much <u>redundancy</u> is needed?

- a. Are the redundant parts <u>separated</u>? <u>Protected</u>?
- b. Are the series parts <u>consolidated</u>? <u>Protected</u>?

IV. Separation from other vital functions.

- a. Is this vital system <u>separated</u> from other vital systems which function independently? Is there <u>separation</u> of vital functions within the system?

V. Does this system endanger other systems? How can this danger be avoided or reduced?

The engineer's judgment and ingenuity are needed to decide whether the protective features implied by the questions are desirable and, if so, how to apply them. This kind of an overall look is less tedious and can be nearly as effective as full scale computerized study.

An analysis of the chilled water system can be used to illustrate the use of this method. The chilled water system provides cooling water to control the temperature of electronic equipment and to cool air conditioning coils. Several chilled water plants cool fresh water which is pumped to the user of chilled water and recirculated back to the plant. There is a chilled water main made up of a supply and a return pipe which forms a loop within the ship.

Now run through the analysis:

I. The system is vital because it cools vital pieces of electronic equipment. These electronics can operate only for a short time without chilled water.

II. Segregation is accomplished by cut-out valves.

a. Vital parts can be segregated because risers from the main serving vital equipment are separate from those carrying non-vital functions. All risers have root valves.

b. There are segregation valves around the loop.

III. The system is redundant; each vital cooling coil is supplied from two segments of the main loop. Each segment can be connected to any or all of the chilled water plants.

a. The chilled water plants are located in separate spaces throughout the ship. They are generally protected by ship's structure.

b. All of the equipment required to cool the water is located in a single space.

IV. Separation from the other vital functions.

a. The chilled water plants are usually located in spaces with other equipment. Risers to vital services are distributed evenly to each segment.

V. Damaged piping could cause water damage.

The analysis shows that there is redundancy, segregation, consolidation and some protection. The designer's question is: Is this too much or too little? It also shows that some thought should be given to locating chilled water plants in separate spaces and to locating chilled water piping to minimize damage to equipment in the event of rupture.

Summary

Naval ships are unique because they are expected to sustain damage in the course of performing their mission. They must continue to operate in spite of damage. Certain functions may be identified which enable the ship to continue operating, they may be called vital functions. Vulnerability experts have classified redundancy, segregation, consolidation and protection as the means of providing protection. Once the vital functions have been identified, these protective measures are used to ensure that they will continue to support the ship's operation. Every engineer can use the list given here and the short evaluation procedure to provide added protection in his design area.

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